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Physics in Perspective

Enrico Fermi in Pisa*

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I discuss the early work of Enrico Fermi (1901–1954) as a student in Pisa at the Scuola Normale Superiore and at the University of Pisa (1918–1922), paying particular attention to the four papers he published during those years and to his *licenza* and doctoral theses.

Key words: Enrico Fermi; Franco Rasetti; Enrico Persico; Adolfo Amidei; Luigi Bianchi; Scuola Normale Superiore; University of Pisa; relativity theory; electromagnetic mass; X-ray diffraction.

Fermi's Education in Pisa

The University of Pisa was founded in 1343 by Pope Clemente VI, while the Scuola Normale Superiore in Pisa was established much later by Napoleon in 1810 as a branch of the École Normale Supérieure in Paris. It began its activities in 1813 as a school for the preparation of secondary school teachers and the promotion of advanced study and research, but closed in 1815 after Napoleon's abdication and exile. It was reopened only in 1846 by the Grand Duke of Tuscany, Leopoldo II of Lorena, as a kind of elite college attached to the University of Pisa. After the unification of Italy in 1861, it became an institution for advanced scientific education and research; finally, in 1932, it was granted administrative autonomy from the University of Pisa. Its restricted student body was and is selected nationally on the basis of severe and impartial competitive examinations and has been a major source of scientific talent for Italy.[1]

Enrico Fermi (1901–1954) was admitted to the Classe di Scienze of the Scuola Normale Superiore in Pisa in 1918, when he was not yet eighteen years old.[2] He already had a broad and deep knowledge of physics owing to his early autodidactic studies, which revealed his precocity.

The engineer Adolfo Amidei (1877–1965), a colleague and friend of Enrico's father, was the first to recognize the extraordinary cleverness of the youth and note his great curiosity about the physical world. Enrico asked Amidei for a book where he could find a scientific explanation of the motions of a spinning top and gyroscope. Amidei answered that he would have to "master a science known as theoretical mechanics; but in

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Fig. 1. Enrico Fermi (1901–1954) at age 16. *Credit*: American Institute of Physics Emilio Segrè Visual Archives.

order to learn it he would have to study trigonometry, algebra, analytic geometry, and calculus."[3] Between the end of 1914 and the summer of 1918, Amidei then advised Enrico (figure 1) on his studies and lent him many excellent and often difficult books on mathematics by Joseph Serret (1819–1885), Ernesto Cesàro (1859–1906), Luigi Bianchi (1856–1928), Ulisse Dini (1845–1918), Giuseppe Peano (1888–1932), and Hermann Grassmann (1809–1877), as well as the *Traité de mécanique* (second edition, 1833) of Siméon-Denis Poisson (1781–1840). He also suggested that he should study infinitesimal analysis to acquire the basic tools needed for a deep understanding of analytical mechanics that he was learning from the book by the Jesuit Andrea Caraffa (1785–1845), *Elementorum physicae mathematicae*, published in 1840.[4] These early studies prepared him to deal with the difficult mathematical formalism he would use in some of his first scientific works on electromagnetism and relativity. Throughout his life, Fermi had a pragmatic attitude towards mathematics, more like a modern theoretical physicist than a mathematical physicist: He always concentrated on the physics of a problem without submerging it under advanced mathematical tools.

Amidei convinced Enrico's parents to allow their son to go to the University of Pisa as a student in the Scuola Normale Superiore because, he explained, there was an important library at the students' disposal there and lectures were offered that were complementary to the ones at the university. Amidei also suggested to Enrico that he study Orest D. Khwolson's five-volume *Traité de physique*[5] to prepare for the entrance examination to the Scuola Normale Superiore.

Fermi's Entrance Examination

On November 14, 1918, with his broad self-taught background in physics and mathematics, Fermi took the entrance examination in Rome, getting excellent marks. His treatment of the topic, "Distinctive Characters of Sounds and Their Causes,"* astonished the three members of the judging commission because of its clarity and profundity and use of advanced mathematical methods in analyzing the problem of a vibrating rod.** Professor Giulio Pittarelli (1852–1934), president of the commission, was so surprised that he called Fermi in for an interview, which ended with him telling Fermi "that in his long career as a professor he had never seen anything like this, that Fermi was a most extraordinary person and was destined to become an important scientist."[6]

The four years that Fermi spent in Pisa, according to his wife Laura, were the most happy and carefree ones of his life.[7] He met Franco Rasetti (1901–2001), another student at the University of Pisa, and established a lifelong friendship with him.[8] They spent a lot of time together, not only discussing physics, but also taking long walks in the nearby mountains, especially in the Apuane Alps (figure 2), which they loved dearly.*** Academically, Fermi already knew most of the subjects being taught, so he had lots of free time to spend in the library of the Scuola Normale Superiore, where he studied the "new physics," especially relativity and quantum theory.

Theoretical Physics in Italy in the Early Twentieth Century

To better understand the novelty of Fermi's researches at Pisa, I must briefly survey Italian physics at the beginning of the twentieth century. There were great Italian physicists in the past, but Italy now was not in the mainstream of European physics.[9] Albert Einstein had recently formulated his theories of special and general relativity, and Niels Bohr, Werner Heisenberg, Erwin Schrödinger, and Paul A.M. Dirac were laying

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* "*Caratteri distintivi dei suoni e loro cause*." Emilio Segrè translated this title less accurately as "Characteristics of Sound"; see Segrè, *Enrico Fermi* (ref. 1), p. 12, and "Distinctive Properties of Sound"; see Segrè, "Biographical Introduction," in Amaldi, *et al.*, ed., *Fermi Collected Papers* (ref. 11), p. xxii.

** Professor R. Vergara Caffarelli has analyzed Fermi's examination solutions and soon will publish them together with his unpublished early writings; see also Vergara Caffarelli, "Enrico Fermi al Liceo Umberto I" (ref. 2), pp. 11–12; Sassi and Sebastiani, "La formazione scientifica" (ref. 2), pp. 99–101; and Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 65–70.

*** Rasetti's mother remembered that her son Franco initiated Fermi's love of the Apuane Alps, taking him up and bringing him back dead tired; see Vergara Caffarelli, "Enrico Fermi, Immagini e Documenti" (ref. 2), p. 23.

Fig. 2. Enrico Fermi, Nello Carrara, and Franco Rasetti in the Apuane Alps in 1922. *Credit*: Amaldi Archives, Dipartimento di Fisica, Università "la Sapienza," Rome; courtesy of American Institute of Physics Emilio Segrè Visual Archives.

the basis of quantum mechanics in other European countries, developing new mathematical methods at the same time. In Italy, by contrast, theoretical physics was not taught in university courses, nor as a consequence was there any research being conducted in theoretical physics. Mathematical physics, however, was a major area of research, and Italian researchers obtained important results in this field. At the same time, Italian mathematicians, especially in Pisa, including Enrico Betti (1823–1892), Ulisse Dini, Vito Volterra (1860–1940), and Luigi Bianchi, were making pioneering contributions to the foundations of modern analysis and geometry.

Mathematical physicists and theoretical physicists approached physical problems quite differently: The former focused on difficult mathematical problems that arose in classical physics, while the latter aimed to understand and interpret phenomena that did not fit into known physical theories. Italian mathematical physicists thus focused on formal mathematical problems. They worked in mathematics departments and seldom discussed their problems with their colleagues in physics departments.

Thus, when Fermi entered the Scuola Normale Superiore in Pisa, very little was known in Italy about relativity and quantum theory. Even though relativity was widely accepted by Italian mathematicians in its formal aspects, both relativity and quantum theory were viewed with scepticism by Italian physicists. Some courses in theoretical physics were introduced only beginning in the mid-1920s, and with his appointment in the University of Rome in 1926, Fermi became the first professor of theoretical physics in Italy.

Fermi's Studies in Pisa

We know quite precisely the books that Fermi read and his interests during his years in Pisa, because he wrote regularly about his studies to his old friend in Rome, Enrico Persico (1900–1969).[10] Thus, we know that just after arriving in Pisa, he already had in mind to reorganize and publish his studies in physics. He kept a little copybook, deposited today in the Domus Galileiana in Pisa, in which he summarized nineteen articles by Einstein, Arnold Sommerfeld, Max von Laue, O.W. Richardson, Niels Bohr, and others, and three of his own papers and part of a published one.[11] One of the unpublished ones bears witness to his interest in experimental problems, discussing a device to measure the wavelength of light. A second copybook bears the title, "Some physical theories" (*Alcune teorie fisiche*),[12] which Fermi kept his entire life and never showed even to his close friends. It contains an extensive bibliography of writings on various topics and summaries of classical mechanics, the electron theory of matter, Max Planck's theory of black-body radiation, and properties of radioactive elements.[13] Fermi later would make fundamental contributions to some of these subjects.

At the end of his first year in Pisa, Fermi was already studying the old quantum theory of Bohr and Sommerfeld, and in January 1920 Professor Luigi Puccianti (1875–1946) asked him to give a lecture in the physics department explaining this theory to his professors. Fermi had already become the most important authority on the new physics in Pisa.

By the end of May 1920, Fermi was thinking about the subject of his doctoral thesis. His correspondence with Persico shows that he wanted to study experimentally the phenomenon of X-ray diffraction by crystals.[14] He was understandably drawn to an experimental topic, given the low state of theoretical physics in Italy, even at the University of Pisa, but where at the same time experimental physics was in the forefront with laboratories well furnished with modern equipment, as was Professor Puccianti's where Fermi worked.

During his thesis work, Fermi also carried out research on the theory of relativity: "I am acting as lecturer,* relativist, and physicist," he wrote to Persico on January 25, 1922.[15] In fact, already a year earlier, in January 1921, when he was a third-year student at Pisa, Fermi had submitted a paper on a problem in relativity theory – his first scientific publication.

Fermi's Early Scientific Works

I will describe these early works of Fermi briefly to show the difficulty of the problems he was able to tackle as a young student.[16] The first four of his published articles reveal

* Fermi delivered a lecture on January 11, 1922, entitled "Il Moderno Orientamento della Fisica e la Teoria della Relatività" ("The Modern Trend of Physics and the Theory of Relativity") at the Università Popolare (People's University). All of the other lectures during January were delivered by professors, none by another student. See Vergara Caffarelli, "Enrico Fermi, Immagini e Documenti" (ref. 2), p. 33.

his increasing interest in general relativity; the last two represent the best of his youthful scientific work.

Fermi's first paper, "On the dynamics of a rigid system of moving charged particles,"[17] deals with an old and controversial problem associated with the electromagnetic mass of the electron. If one assumes that an electron is a rigid, uniformly-charged, spherical shell of electricity, and if one computes the momentum of its associated electromagnetic field, one finds that the electromagnetic inertia of a slowly-moving electron is 4/3 times the ratio of its total energy u to the square of the speed of light c. This differs by a factor of 4/3 from the well-known result from special relativity, a discrepancy that Fermi resolved in his fourth published paper, which I will discuss below. Meanwhile, he generalized this result for the case of an arbitrarily-extended charge distribution. O.W. Richardson, in his book on the electron theory,[18] which Fermi knew well and was inspired by it, noted that to carry out this generalization, the "calculations are very complicated."[19] Fermi's first work thus can be viewed as a formal exercise that displayed his surprising skill in carrying out difficult calculations.

Two months later, in March 1921, Fermi completed his second paper, "On the electrostatics of a uniform gravitational field and the inertia of electromagnetic masses,"[20] which dealt with the general-relativistic effects of a uniform gravitational field on electrostatic phenomena. He also discussed the problem of inertial masses (*masse pesanti*), defined as the ratio of the gravitational force to the gravitational acceleration of electromagnetic systems. His striking result was to show that the inertial mass differs from the electromagnetic mass, the former agreeing with Einstein's equivalence principle, the latter differing from it by a factor of 4/3 for a spherical charge distribution. Handwritten notes on Fermi's calculation by Persico state that, "Such a discrepancy did not stop worrying him, and he did not hide his happiness when he found out the explanation."[21] It is remarkable that Fermi could employ so easily the complex tools of general relativity, in particular the differential geometry of non-Euclidean spaces, but we must remember that in Pisa he had met the great mathematician, Professor Luigi Bianchi, who since 1918 was Director of the Scuola Normale Superiore. Fermi had attended Bianchi's course on analytic geometry during his first year in Pisa, and had studied Bianchi's lectures for it.[22] During his fourth year, Fermi also attended Bianchi's lectures on differential geometry,[23] but he did not like them very much; he found them boring, because they seemed to him to be too formal and divorced from practical applications. As he wrote to Persico, "I will have to pass the examination in higher analysis (differential geometry) which is a terrific bore, in which the problems studied are chosen by the sole criterion that they should lack all [practical] interest."[24]

Fermi's most important early work was his third publication, "On the phenomena occurring close to a world line,"[25] which he probably completed before January 1922. This is a brilliant paper whose main result appears in textbooks on general relativity as the Fermi theorem, Fermi coordinates, or the Fermi-Walker parallel-transport theorem.[26] Emilio Segrè called it "Fermi's first accomplishment of permanent value";[27] it was first cited in Tullio Levi-Civita's book, *Calcolo Differenziale Assoluto*, published in Italian in 1925 and in English in 1927 as *The Absolute Differential Calculus*,[28] which provided rapid international dissemination of Fermi's result.

Fermi published his fourth paper, in which he solved the puzzling problem of the 4/3 factor in the electromagnetic mass of the electron, in three different journals with minor changes and with nearly the same title, "Correction of a serious discrepancy between the electrodynamic and relativistic theory of electromagnetic masses."[29] Persico reported that Fermi was very proud of this work:

> Prof. [Giovanni] Polvani [1872–1970] remembers that the question was debated, one winter evening of 1922, in Pisa, while Fermi, Puccianti, Polvani and other friends walked through via San Frediano from the University [which was in the old building in Torricelli square] to the Scuola Normale Superiore. Here the company parted without having reached any satisfactory conclusion. In the following two days, Fermi did not appear in the Institute of Physics. On the third day he arrived with a paper, ready for publication, entitled "Correzione di una grave discrepanza...." Puccianti, who had emphasized the need for a clarification, was enthusiastically happy.[30]

That Fermi himself recognized the importance of his result is clear, since one of the journals to which he sent it for publication was the respected *Physikalische Zeitschrift*. Fermi knew that Italian journals such as *Nuovo Cimento* and *Rendiconti dell'Accademia dei Lincei*, in which he had published his first three papers, were seldom read by foreign physicists. In fact, Fermi's result was nearly forgotten and was obtained later by other physicists; it can be found today, for example, in J. David Jackson's well-known textbook on electrodynamics.[31] Fermi traced the "serious discrepancy" to the definition of the concept of a rigid body:

> the difference between the mass obtained in two different ways stems from the idea of a rigid body contradicting the principle of relativity, which is applied in the theory of electrodynamics... and leads to a mass of 4/3 u/c^2, while a more justified idea of rigid body, agreeing also with relativity, leads to the value u/c^2 [where u is its electrostatic energy]....[32]

By applying Hamilton's variational principle, Fermi showed that the correct concept of a rigid body is like the usual one in kinematics in the particle's rest frame. He thus resolved the "serious discrepancy" and obtained a consistent picture of a relativistic electron, although even today the stability of the electron is not understood.

Fermi's Theses

From the beginning of 1922, Fermi also was working on his theses for the *licenza*, the Scuola Normale leaving examination, and for his doctoral degree (*laurea**) from the University of Pisa.[33] Despite the work these required, as well as his work on the above publications, Fermi wrote to Persico that, "As a physicist, my main activity consists in

* The *laurea* is conferred after completion of four years of university courses and hence is not equivalent to the Ph.D. degree; however, it carries the doctoral title, and in this sense is a doctoral degree.

doing nothing, because after all I think that Boltzmann statistics do not absolutely exclude the possibility that my dissertation could produce itself by thermal agitation—although such a possibility does not seem very probable."[34]

Licenza

Fermi's *licenza* thesis was on "A theorem of probability calculus and some of its applications."[35] His starting point was a theorem in probability theory due to Pierre Simon de Laplace (1749–1827) and known today as the central-limit theorem, which deals with the problem of determining the distribution function of a sum of a large number of independent random variables, or as Fermi wrote, "a lot of incoherent addends" ("*molti addendi incoerenti*"). Fermi proved a generalization of this theorem,* and he applied it, as an example, to a classic problem in the theory of games of chance, that of a gambler with an infinite sum of money playing against one with a finite sum. Fermi called these two gamblers Pietro and Paolo and described their respective economic status with the words, "Pietro is infinitely rich, Paolo has only *a* liras."** By applying Fermi's theorem, one can compute the probability that Paolo will lose all of his money. To prove his theorem, Fermi had to solve an integral equation of the second kind, but as he noted, "Even though I tried hard, I did not succeed in solving it completely, but only in an approximate way."*** His approximate method was questioned closely by some mathematicians on the judging commission because of its lack of rigor.[36] Fermi then went on to consider the problem of "a comet with an elliptical orbit crossing that of Jupiter."**** Owing to gravitational forces, the comet's motion is perturbed by Jupiter and its orbit may become parabolic or hyperbolic and the comet may even hit Jupiter. Fermi applied his theorem and determined the probabilities of all of these occurrences. The judging commission, composed among others of Bianchi and Puccianti, received Fermi's manuscript on June 20, 1922 (figure 3).

Doctoral Thesis

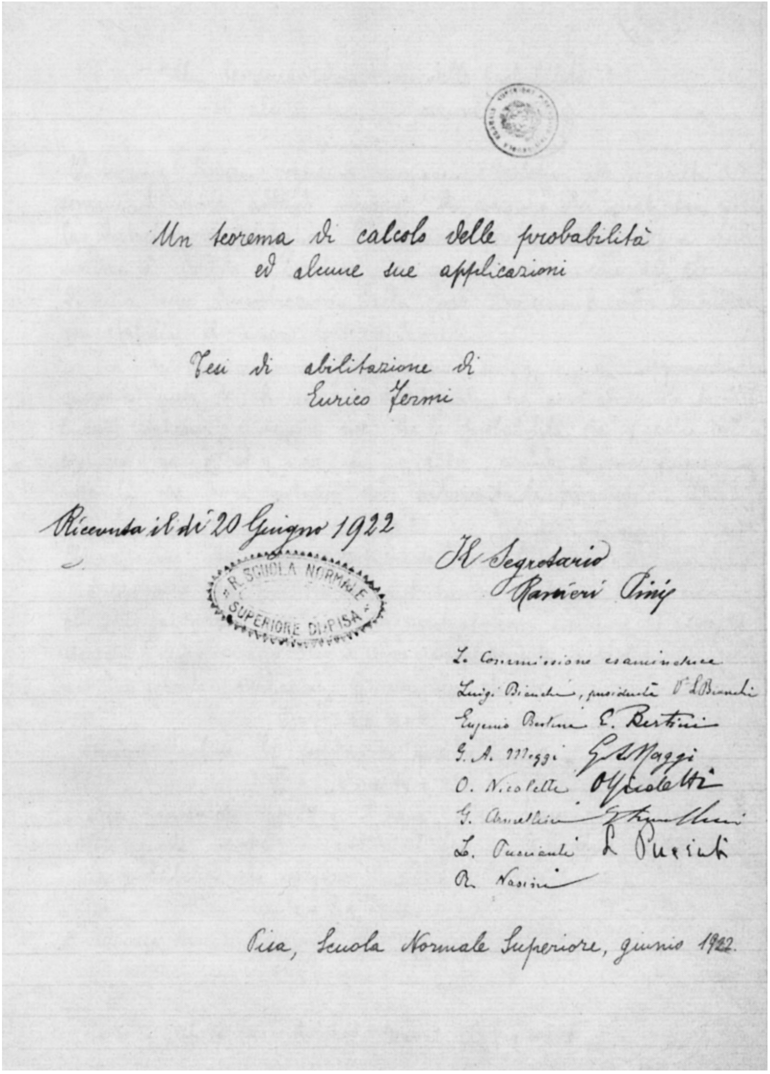
I have noted above that Fermi had been thinking about the subject of his doctoral thesis since 1920,[37] and at the end of that year he was already doing experimental work for it. As he wrote to Persico, "I have been in Pisa for more than twenty days and have already started my work on Roentgen crystallography. The first step was to protect

* Fermi considered n independent and identically distributed continuous random variables, x_1, $x_2, \ldots x_n$, with a variance k^2. Then he determined the probability that at least one of the n random variables x_1, $x_1 + x_2, x_1 + x_2 + x_3, \ldots, x_1 + x_2 + \ldots x_n$ exceeds a given positive number a provided that $a \geq k$.

** "*Ora Pietro è infinitamente ricco, Paolo possiede soltanto a lire.*"

*** "*Per quanti sforzi abbia fatto non mi è riuscito di risolverla altro che in via d'approssimazione*"; see Fermi, "Un teorema di calcolo" (ref. 35), p. 234.

**** "*una cometa ellittica la cui orbita interschi quella di Giove.*"


Un teorema di calcolo delle probabilità
ed alcune sue applicazioni

Tesi di abilitazione di
Enrico Fermi

Ricevuta il dì 20 Giugno 1922

R. SCUOLA NORMALE SUPERIORE DI PISA

Il Segretario
Ranieri Pini

La Commissione esaminatrice
Luigi Bianchi, presidente L Bianchi
Eugenio Bertini E. Bertini
G. A. Maggi G A Maggi
O. Nicoletti O Nicoletti
G. Armellini
L. Puccianti L Puccianti
R. Nasini

Pisa, Scuola Normale Superiore, giugno 1922.

Fig. 3. The title page of Fermi's *Licenza* thesis. It is dated 20 June 1922, and the members of the judging commission with their names and signatures are listed on the lower right-hand side. The first name and signature is that of Luigi Bianchi, president of the judging commission. *Credit*: Historical Archive, Centro Archivistico della Scuola Normale Superiore, Pisa.

myself and my collaborators from the action of the X-rays."[38] Fermi then described to Persico various technical problems he had to solve in setting up his experiments, which clearly showed that Fermi was not only an extraordinary theoretician but also a highly talented experimentalist, as he again demonstrated a dozen years later in his neutron experiments at the University of Rome with his famous group (figure 4), the boys of

Fig. 4. Emilio Segrè, Enrico Persico, and Enrico Fermi (*left to right*), three of "the boys of via Panisperna" in Rome (1927). *Credit*: American Institute of Physics Emilio Segrè Visual Archives, Segrè Collection.

via Panisperna (*I ragazzi di via Panisperna*). Fermi, unlike other great theoreticians before and since, was able to move easily between theory and experiment and make highly original contributions to both.

Fermi's doctoral thesis was entitled "Studies on Röntgen Rays" ("*Studii sopra i raggi Röntgen*") and consisted of four chapters.[39] The first described the general properties of X rays, the next two dealt with the theory of X-ray diffraction by crystals, and the last one reported his experimental results. The first and last chapters, but not the middle two, were published in *Nuovo Cimento*.[40] Indeed, the handwritten copy of Fermi's thesis was believed to have been lost, because many unsuccessful attempts were made to find it in various archives. However, in 1990 Professor R. Vergara Caffarelli found it at the University of Pisa,* and he is now analyzing its contents, paying particular attention to the unpublished second and third chapters.

* Fermi's thesis had been filed in the archives of the University of Pisa under the misspelled name "Terni"!

Fermi's second chapter is entitled "On the theory of thermal effects on Röntgen-ray diffraction by crystals" ("*Sulla teoria dell'influenza dell'agitazione termica sopra la diffrazione dei raggi Röntgen nei cristalli*"). It deserves comment, because eight years earlier, in 1914, Peter Debye had published the same theory in the *Annalen der Physik* under the title, "X-ray Interference and Thermal Motions."[41] Fermi cited Debye's papers of 1912 and 1913,[42] which dealt respectively with his famous theory of the specific heats of solids and with X-ray scattering and noted that, "starting from Debye's theory of thermal motion in solids, I want to improve Debye's theory of diffraction." Now, since Debye's paper of 1914 treats exactly this problem, analyzing the effect of thermal motion on the diffraction of X rays by crystals, the question arises as to why Fermi did not cite Debye's paper in his thesis. We know that he was aware of it, since among Fermi's papers that his wife Laura deposited in the Domus Galileiana in Pisa, Professor Vergara Caffarelli found two handwritten drafts of papers in which Fermi cites Debye's paper of 1914 and develops in a clear and simple way "An improvement of Debye's theory of thermal effects on Röntgen-ray diffraction by crystals."* Professor Vergara Caffarelli believes that Fermi arrived independently at the same results that Debye had and drafted a paper on the subject, but then saw Debye's paper appear in print and hence decided not to publish his own paper.[43] Moreover, as he was completing his thesis, Fermi probably was not certain that the experimental results he had obtained were good enough to meet the commission's expectations for experimental work, so given the possibility that the commission would criticize the experimental part of his thesis, he probably did not cite Debye's paper in his thesis because he wanted to enhance the scientific value of its theoretical part. In any case, Fermi himself was dissatisfied with his thesis. As he wrote to Persico, "I have been and still am exceedingly busy, partly because of my dissertation, which by the way has become a first-class mess."[44]

Fermi received his doctoral degree from the University of Pisa with the highest distinction, *cum laude*, on July 7, 1922. Three days later, he also passed the *licenza* examination of the Scuola Normale Superiore *cum laude*. Soon thereafter he returned home to Rome, and after extended stays in Göttingen, Leiden, and Florence, began his extraordinary career at the University of Rome in 1926.

Acknowledgments

I thank Riccardo Barbieri, who on behalf of the Organizing Committee of the International Conference on Enrico Fermi and Modern Physics, Pisa, Italy, October 18–20, 2001, invited me to give the talk on which this paper is based. I thank R.K.P. Zia and B. Schmittmann, Department of Physics, Virginia Polytechnic Institute and State University, for their hospitality while I was working on my paper. Finally, I thank Roger H. Stuewer for his careful editorial work on it.

* "*Un perfezionamento della teoria di Debye dell'influenza dell'agitazione termica sopra la diffrazione dei raggi Röntgen nei cristalli*."

References

1 This account is based partially on that of Emilio Segrè, *Enrico Fermi Physicist* (Chicago: University of Chicago Press, 1970), p. 14.

2 Earlier accounts of Fermi's student years in Pisa appear in Laura Fermi, *Atoms in the Family: My Life With Enrico Fermi* (Chicago: University of Chicago Press, 1954), pp. 13–26; Pierre de Latil, *Enrico Fermi: The Man and His Theories*, translated by Len Ortzen (New York: Paul S. Eriksson, 1965), pp. 21–26; Segrè, *Enrico Fermi* (ref. 1), pp. 1–24; and Emilio Segrè, "Fermi, Enrico," in Charles Coulston Gillispie, *Dictionary of Scientific Biography*, Vol. IV (New York: Charles Scribner's Sons, 1971), pp. 576–583. Recent accounts are Bruno Pontecorvo, *Enrico Fermi* (Pordenone: Edizioni Studio Tesi, 1993), pp. 17–24; G.F. Bassani, "Enrico Fermi alla Scuola Normale," *Normale: Bollettino dell'Associazione Normalisti* **1–2** (Ottobre 1998), 20–25; M.C. Sassi and F. Sebastiani, "La formazione scientifica di Enrico Fermi," *Giornale di Fisica* **40**, No. 2 (Aprile–Giugno 1999), 89–113; F. Sebastiani, F. Cordella, and A. De Gregorio, *Enrico Fermi: Gli Anni Italiani* (Roma: Editori Riuniti, 2001), pp. 15–107; R. Vergara Caffarelli, "Enrico Fermi al Liceo Umberto I di Roma e all'Università di Pisa," *Il Nuovo Saggiatore* [Bulletin of the Italian Physical Society] **17**, No. 5–6 (2001), 8–15, lecture at the Memorial Conference "Enrico Fermi, maestro e didatta," Villa Monastero, Varenna (Lake Como), Italy, July 2, 2001; available on-line at <www.sif.it>; and R. Vergara Caffarelli, "Enrico Fermi, Immagini e Documenti inediti [Unpublished Pictures and Documents]," Catalogue of the Exhibition at Limonaia di Palazzo Ruschi, Pisa, October 18–28, 2001 (Pisa: La Limonaia and Edizioni Plus, Università di Pisa, 2002) [with text in English].

3 Quoted in Segrè, *Enrico Fermi* (ref. 1), p. 9.

4 Andrea Caraffa, *Elementorum physicae mathematicae* (Roma: G.B. Marini, 1840).

5 Orest Daniilovich Khvolson, *Traité de physique*, traduit par E. Davaux, 5 Vols. (Paris: A. Hermann, 1906–1914). For a discussion of Khvolson's *Traité* as well as Caraffa's *Elementorum physicae mathematicae*, see Sassi and Sebastiani, "La formazione scientifica" (ref. 2), pp. 92–95, and Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 54–57, 59–65; for further discussion of Khvolson's book, see C. Bernardini, "Enrico Fermi e il trattato di O.D. Chwolson," *Il Nuovo Saggiatore* [Bulletin of the Italian Physical Society] **17**, No. 5–6 (2001), 15–19, lecture at the Memorial Conference "Enrico Fermi, maestro e didatta," Villa Monastero, Varenna (Lake Como), Italy, July 2, 2001; available on-line at <www.sif.it>.

6 Quoted in Segrè, *Enrico Fermi* (ref. 1), p. 13.

7 Laura Fermi, *Atoms in the Family* (ref. 2), p. 22.

8 Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 71–73.

9 I am summarizing the careful discussion by Sassi and Sebastiani, "La formazione scientifica" (ref. 2), pp. 89–91, and Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 15–47.

10 Fermi's letters to Persico between 1917 and 1926 have been translated into English by E.G. Segrè and are published in Segrè, *Enrico Fermi* (ref. 1), Appendix 1, pp. 189–213.

11 E. Fermi, "Sulla dinamica di un sistema rigido di cariche elettriche in moto traslatorio," *Nuovo Cimento* **22** (1921), 199–207; reprinted in Edoardo Amaldi, Enrico Persico, Franco Rasetti, and Emilio Segrè, ed., *Enrico Fermi, Collected Papers (Note e Memorie)*, Vol. I. Italy 1921–1938 (Chicago: University of Chicago Press and Roma: Accademia Nazionale dei Lincei, 1962), pp. 1–7. See also Vergara Caffarelli, "Enrico Fermi al Liceo Umberto I" (ref. 2), pp. 74–82.

12 For an analysis of this copybook, see Sassi and Sebastiani, "La formazione scientifica" (ref. 2), pp. 104–109, and Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 74–82.

13 Sassi and Sebastiani, "La formazione scientifica" (ref. 2), pp. 104–109.

14 Fermi to Persico, May 30, 1920, and November 29, 1920, in Segrè, *Enrico Fermi* (ref. 1), pp. 194–196.

15 Fermi to Persico, January 25, 1922, in Segrè, *Enrico Fermi* (ref. 1), p. 197.

16 I am following closely the discussion by F. Cordella and F. Sebastiani, "Il debutto di Enrico Fermi come fisico teorico: i primi lavori sulla relatività (1921–1922/23)," *Quaderno di storia della fisica*, No. 5 (1999), 69–88, and Sebastiani, Cordella, and De Gregorio, *Enrico Fermi* (ref. 2), pp. 89–107.

17 Fermi, "Sulla dinamica di un sistema rigido"; reprinted in Amaldi, *et al.*, ed., *Fermi Collected Papers* (ref. 11), pp. 1–7.

18 O.W. Richardson, *The Electron Theory of Matter*, second edition (Cambridge: Cambridge University Press, 1916).
19 *Ibid*., p. 255.
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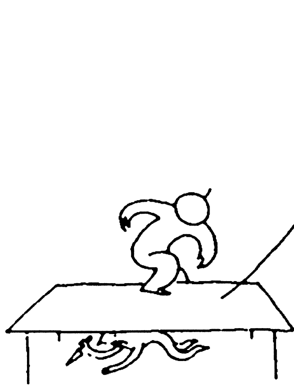

PROGRAMME
FOR
LIVING

Clear the table.
Climb the peak.
Seek the able.
Fear the weak.

Piet Hein